

QCD Studies in ATLAS



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On behalf of the ATLAS Collaboration

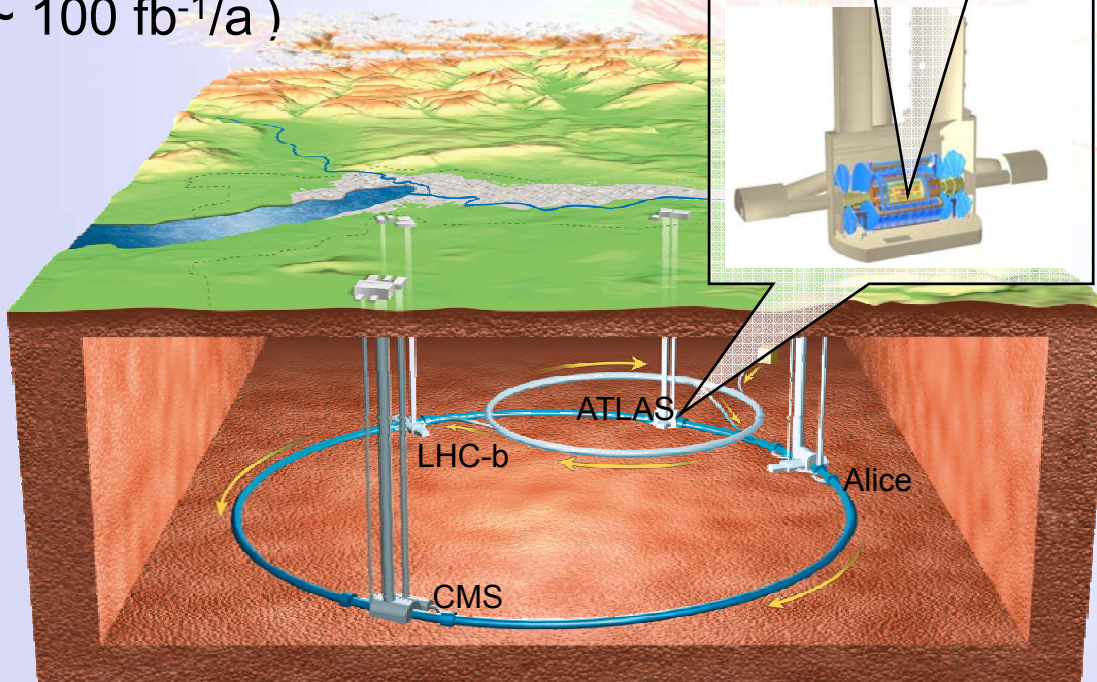
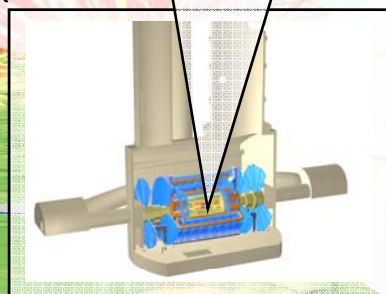
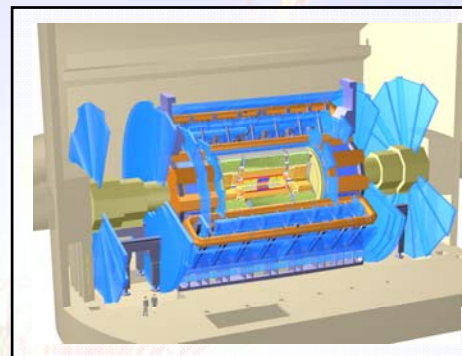


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LHC and ATLAS

- Synchrotron with 27km circumference
- pp collisions at $\sqrt{s} = 14\text{TeV}$
- Low Luminosity: $2 \cdot 10^{33} \text{cm}^{-2} \text{s}^{-1}$ ($\sim 20 \text{fb}^{-1}/\text{a}$)
- High Luminosity: $10^{34} \text{cm}^{-2} \text{s}^{-1}$ ($\sim 100 \text{fb}^{-1}/\text{a}$)



- General purpose detector
- 42m x 25m x 25m
- Mass: 7000t

- Precision measurements with InDet, Calo, Muons within $|\eta| < 2.5$
- Calorimetry coverage $|\eta| < 5$
- Jet Energy Resolution: $50\%/\sqrt{E} + 3\%$ (central)



QCD at ATLAS

- LHC is a QCD Machine
 - Properties of initial partons determined by strong interactions inside the protons (PDF)
 - Highest cross-sections for QCD processes
 - Background to most processes
 - QCD corrections to all processes
 - Final state rarely colour singlet
 - strong interactions of FS with proton remnant
- QCD is of utmost importance at LHC
- LHC is a discovery machine
 - Unprecedented energy range and luminosity
 - SM Higgs well within coverage
 - Many alternative scenarios:
 - SuperSymmetry
 - Technicolour
 - Contact interactions
 - Leptoquarks
 - Compositeness
 - ... many more
- Exciting possibilities for new physics
- QCD (and SM) often take the back seat
- QCD (and SM) will have to be measured precisely at LHC energies



QCD at ATLAS

- Many interesting subjects, e.g.
 - PDF measurements (proton structure)
 - Jet studies (reconstruction, rates, cross sections...)
 - Fragmentation studies
 - Diffractive physics
 - α_s measurements
- Here: Discussing state of some picked examples
 - Jet reconstruction
 - Jet cross section measurements
 - Diffractive Luminosity measurement



Jet Reconstruction

- Jets in the final state dominant signature of strong interactions
- General task: Transform calorimeter response into four-vectors representing the properties of a jet/parton
- Jet energy has to be measured as precise as possible
- Reconstruction of jets, calibration of energy measurement essential to a multitude of measurements



Jet Reconstruction

- **I Calo Reco**
 - Shower containment
 - Electronic noise
 - Pile-up
 - Particle separation and Id
- **II Jet Reconstruction**
 - Issues
 - Reco algorithm (k_t , cone) ?
 - Input (towers, clusters) ?
 - Jet size
 - Overlap
 - Used Reco Algorithms
 - Cone (w+w/o seeds), seed cut 1-2 GeV in E_t , $R = 0.4 \dots 1$
 - K_t w/o preclustering, $R = 0.4 \dots 1$
 - Typically cut $E_t > 20$ GeV on final jets
- **III Calibration Calo → Particles:**
 - Global jet calibration
 - Reconstruct jet in calo
 - Match reco jet with true jet
 - Fit calibration function in η, E from di-jets
 - Local hadron calibration
 - Calibrate calo clusters to true particle scale
 - Form jets from calibrated clusters
 - Apply jet-based correction to particle level
- **IV Calibration Particles → Partons**
 - Out of cone corrections
 - Parton-jet matching in di-jets
 - E_t balance in γ +jet events
 - In situ corrections from W, top, ... masses
 - Underlying event compensation
 - Flavour dependence (b, udsc, g)



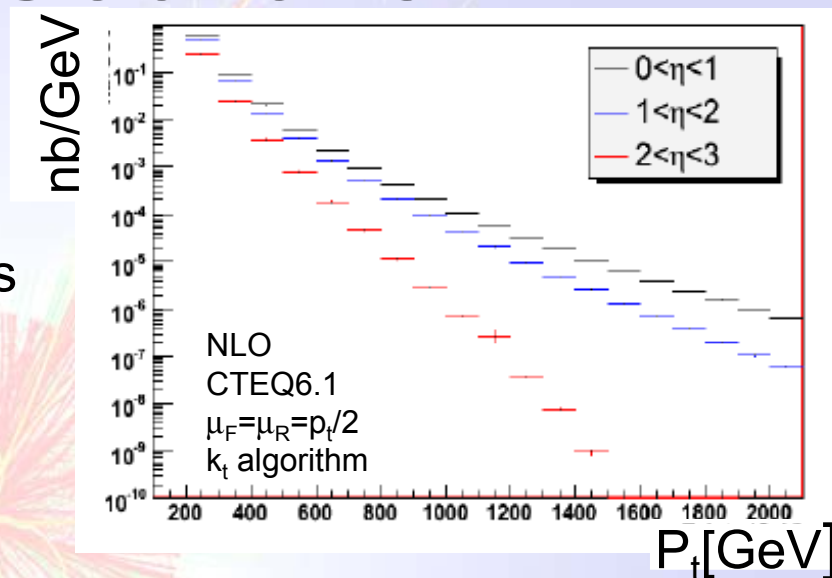
Jet Cross Sections

- Inclusive jet cross sections one of the early (low integrated luminosity) analyses at ATLAS
- Measurement of α_s possible
- Sensitive to new phenomena
- QCD jets are background to almost all interesting physics processes
- Understanding of QCD jets crucial for discovery of new phenomena
- Here:
 - Estimation of expected precision
 - Focus on low luminosity ($L \approx 10^{33} \text{ cm}^{-2} \text{ s}^{-1}$)



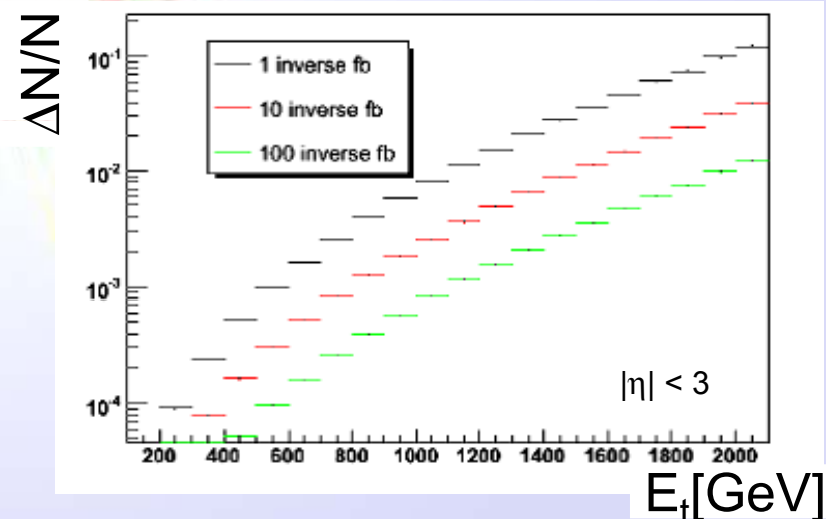
Jet Cross Sections

- Jet p_t spectra for different η
- Rapid decrease for higher p_t
- High p_t region sensitive to new physics
- Considered errors:
 - statistical
 - experimental
 - theoretical



Statistical Errors

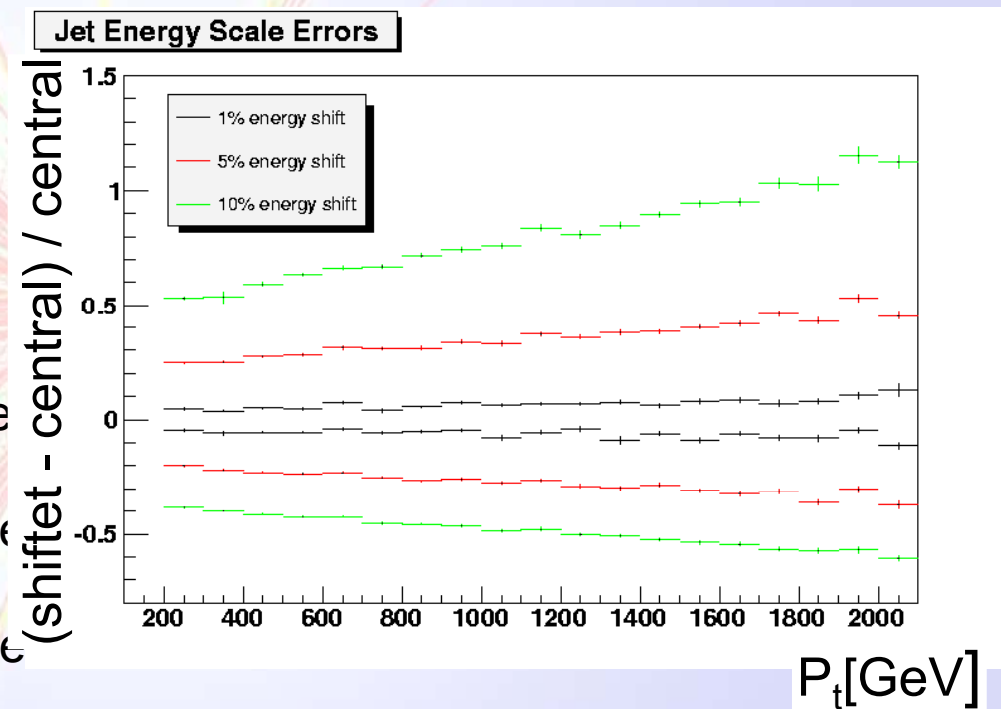
- Only jets with $|\eta| < 3$ considered
- Naïve Error Estimation $\Delta N = \sqrt{N}$
- Plotted: $\Delta N/N$ for different L
- 1% error at $p_t \approx 1 TeV$ with $1 fb^{-1}$
- For $3.2 < |\eta| < 5$ error up to 10%



Jet Cross Sections

Experimental Errors

- Several sources:
 - Luminosity measurement
 - Jet Energy Scale
 - Jet Resolution, UE, trigger efficiency
 - ...
- Jet Energy Scale:
 - 1% uncertainty results in 10% error on σ
 - 5% uncertainty result in 30% error on σ
 - 10% uncertainty result in 70% error on σ
 - If known to 1-2%, experimental errors not dominant



Jet Cross Sections

Theoretical Errors

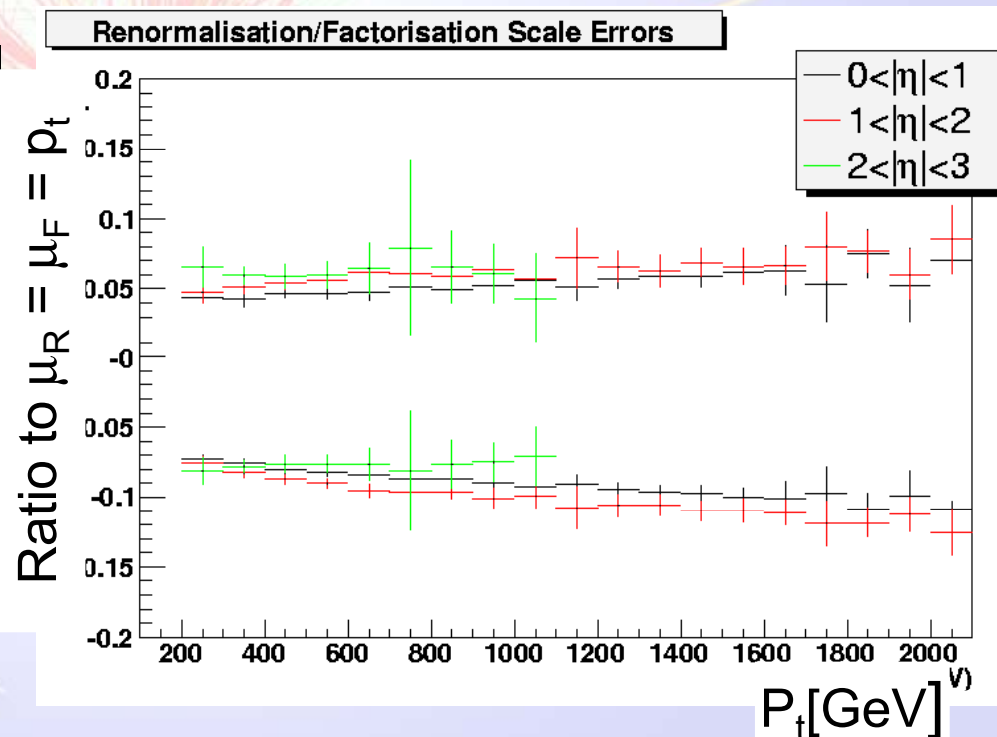
- Cross section is convolution of PDF and hard interaction:

$$\sigma = \sum_{a,b} \int dx_1 dx_2 f_a(x_1, \mu_F) f_b(x_2, \mu_F) \hat{\sigma}_{a,b}(x_a, x_b, \mu_R)$$

- Can be calculated in NLO
- Two main sources of theoretical errors (CDF) :

- scale uncertainties
 - Factorisation μ_F
 - Renormalisation μ_R
- PDF uncertainties

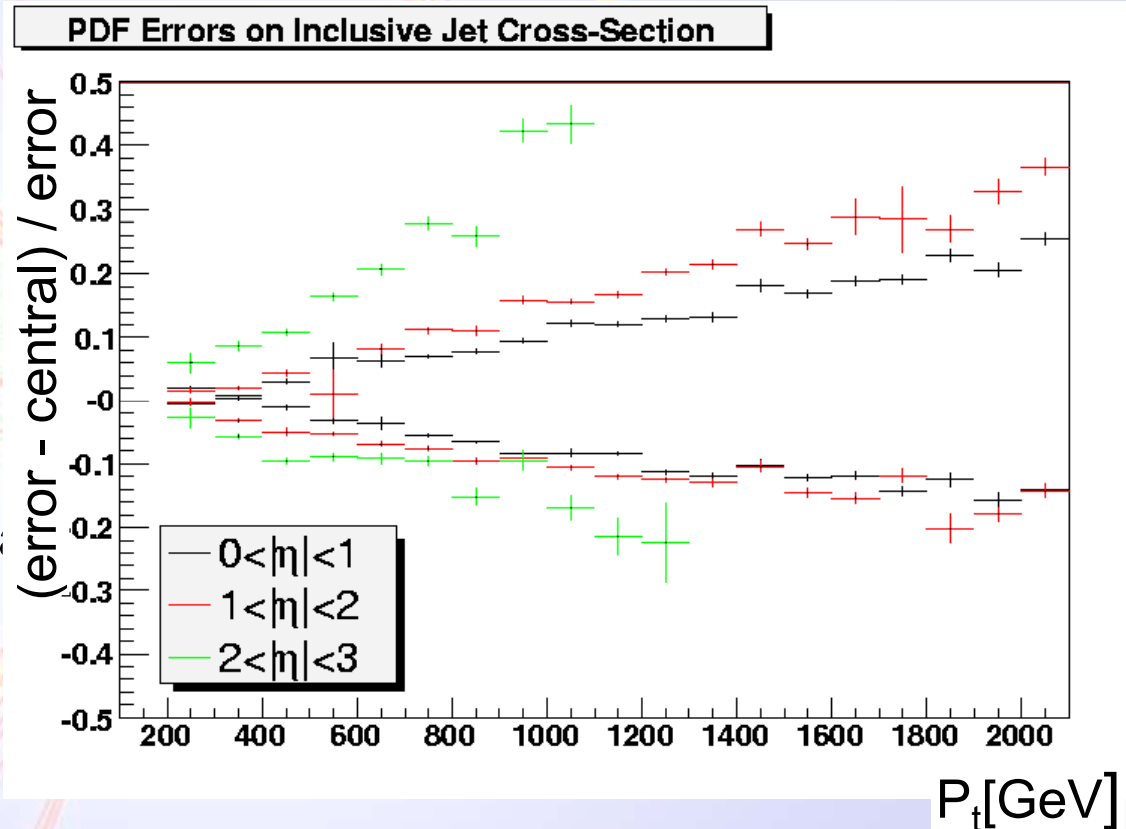
- Scale uncertainties:
 - independent variation of μ_F and μ_R within $p_t^{\max}/2 < \mu < 2p_t^{\max}$
 - $\sim 10\%$ uncertainty at 1TeV



Jet Cross Sections

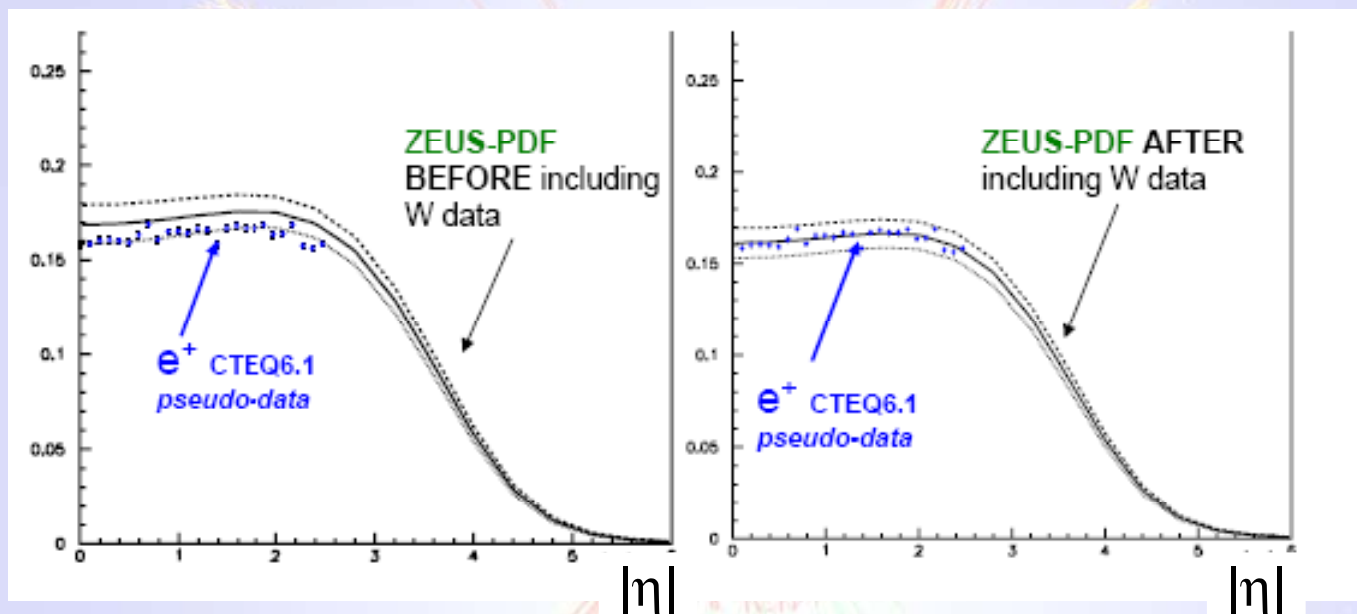
Theoretical Errors

- PDF uncertainties dominant
- Uncertainty evaluation using CTEQ6, 6.1
- Largest uncertainty: high x gluons, in DIS only indirectly accessible
- Related error sets: 29, 30
- Comparison: Best fit with 29, 30
- k_t clustering algorithm
- At $p_t \approx 1$ TeV around 15% uncertainty



Jet Cross Sections

Constraining the PDF at LHC



- W and Z cross section predicted precisely
- Main uncertainty: At $Q^2 \approx M_Z^2$ with $x \approx 10^{-2}$ - 10^{-4} gluon PDF relevant
- Asymmetry is gluon PDF independent \rightarrow benchmark test
- 1M W events ($\sim 200\text{pb}^{-1}$) generated, CTEQ6.1, ATLFAST, 4% exp. error
- 'Measurements' detector corrected and entered into Zeus PDF fit
- Error on λ parameter ($x \cdot g(x) \sim x^{-\lambda}$) reduced by 35%



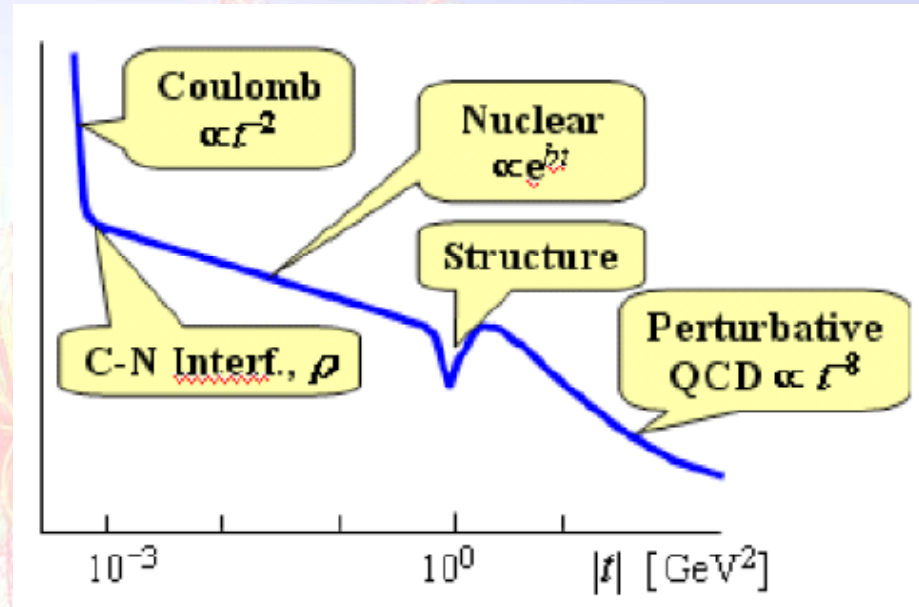
Luminosity Measurement

- Luminosity determination: Leading uncertainty for many cross section measurements
- QCD processes can be used to determine LHC luminosity
- Aim: 2-3% precision of Luminosity measurement
- Options:
 - LHC beam parameter measurements outside the experimental areas, 5-10% accuracy, improving
 - QED cross sections (lepton pair production via $\gamma\gamma$), low event rate, theoretical uncertainties (PDF, fixed order calculation), >5% accuracy
 - Elastic scattering via QED and QCD, requires coverage at very high η -values (Roman Pots), planned for ATLAS
 - UA4: Absolute measurements with 3% accuracy achieved



Luminosity Measurement

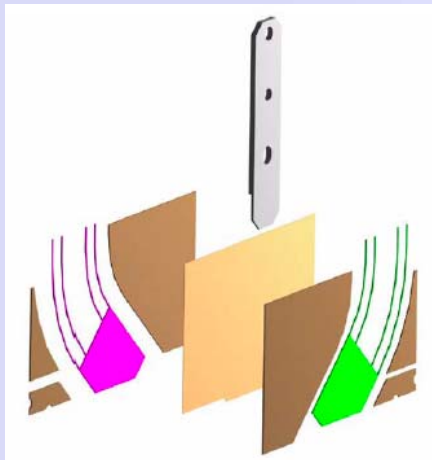
- t dependence of the cross section
- Fit of measured event rate in C-N interference region yields $L, \sigma_{\text{tot}}, \rho, b$
- Requires measurements down to $t \sim 6.5 \cdot 10^{-4} \text{ GeV}^2$ ($\theta \sim 3.5 \cdot 10^{-6}$)
- Detectors necessary which
 - Are close to the beam (1.5mm for $z=240\text{m}$)
 - Have a resolution well below $100 \mu\text{m}$
 - Have no significant inactive edge



$$\frac{dN}{dt}(t \rightarrow 0) = L\pi \left(\frac{-2\alpha}{|t|} + \frac{\sigma_{\text{tot}}}{4\pi} (i + \rho) e^{-b|t|/2} \right)^2$$

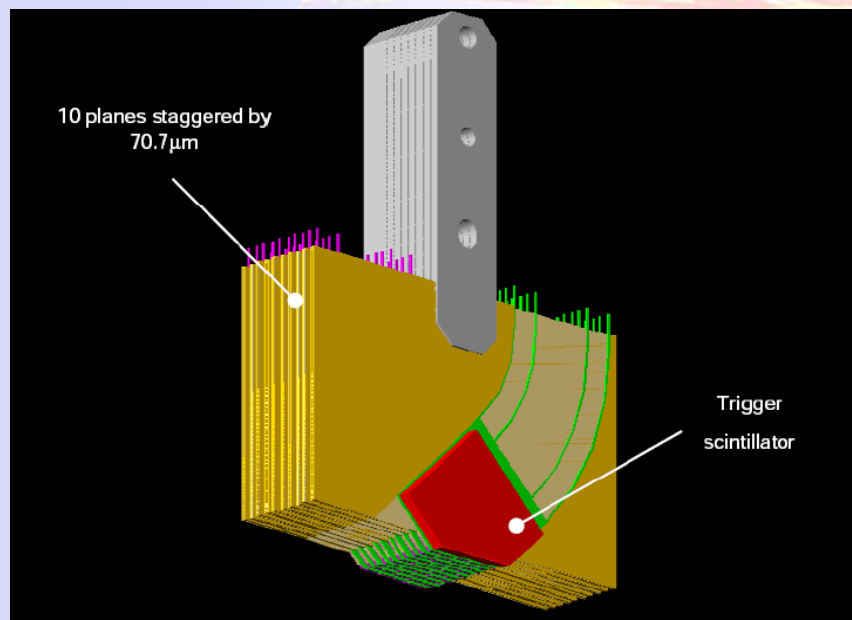


Luminosity Measurement



Roman pot design: scintillating fibres

- Square fibres 0.5mm x 0.5mm
- 2 x 64 fibres on ceramic substrate
- U/V - geometry with 90° tilt
- 10 double sided modules



Luminosity Measurement

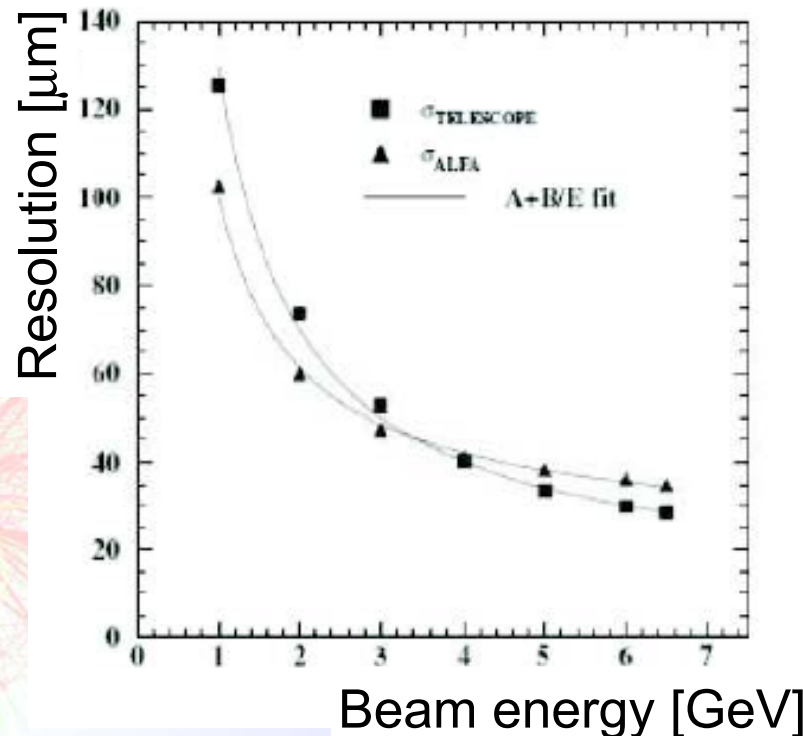
Performed Tests

Spatial resolution

- scales with $1/E$
- For LHC Energies $\sim 20 \mu\text{m}$
- Insensitive edges $< 30 \mu\text{m}$

Luminosity Fit

- 10M events FullSim
- Fit of t dependence
- Comparison with input parameters:
 - excellent agreement
 - error on L 1.5%
 - large correlations between parameters



Parameters	input	fitted	error	correlation
L	$8.124 \cdot 10^{26}$	$8.162 \cdot 10^{26}$	1.5%	
σ_{tot}	100 mb	101.1 mb	0.74%	99%
b	18 GeV^{-2}	17.95 GeV^{-2}	0.59%	64%
ρ	0.15	0.1502	4.24%	92%

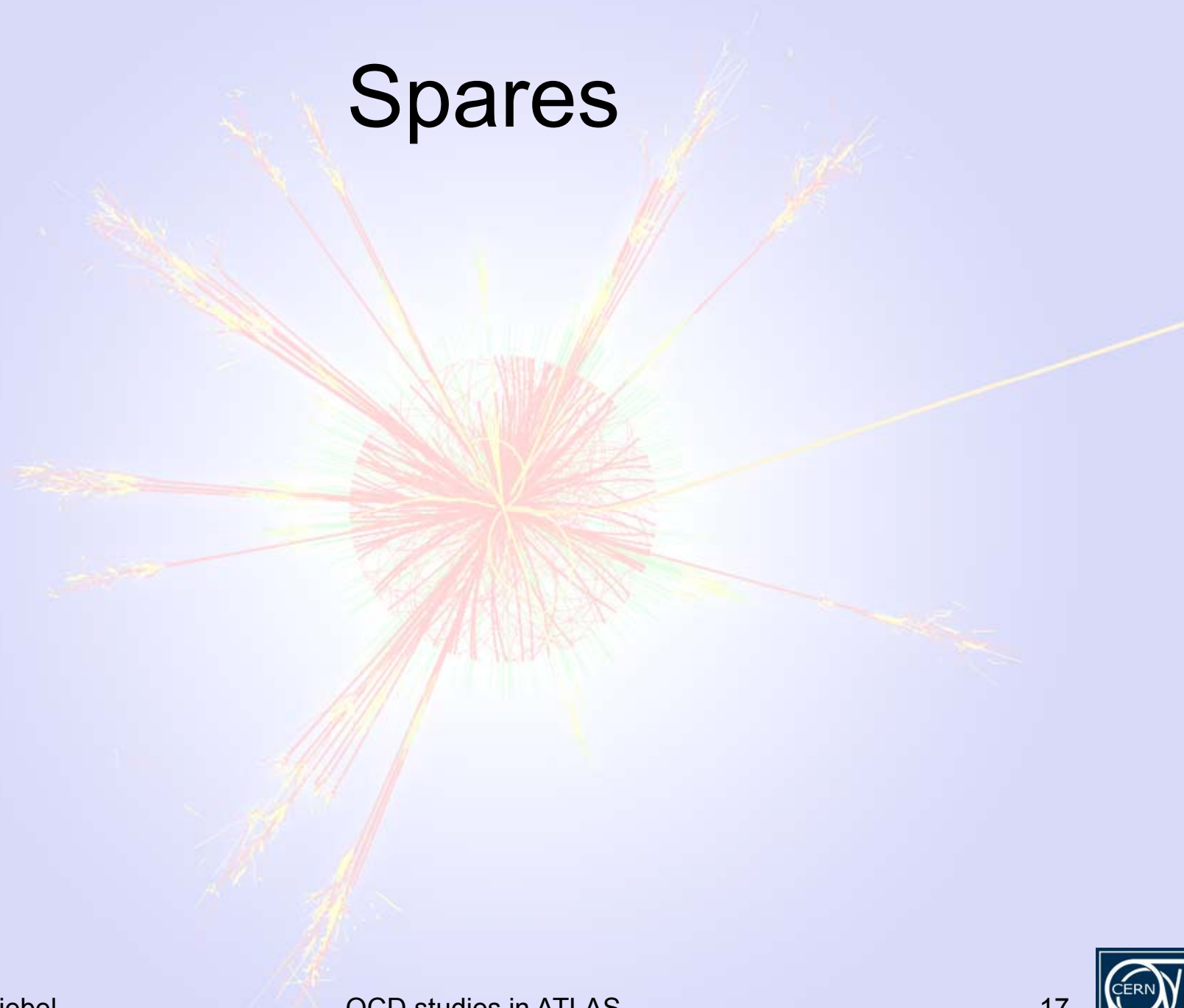


Conclusions

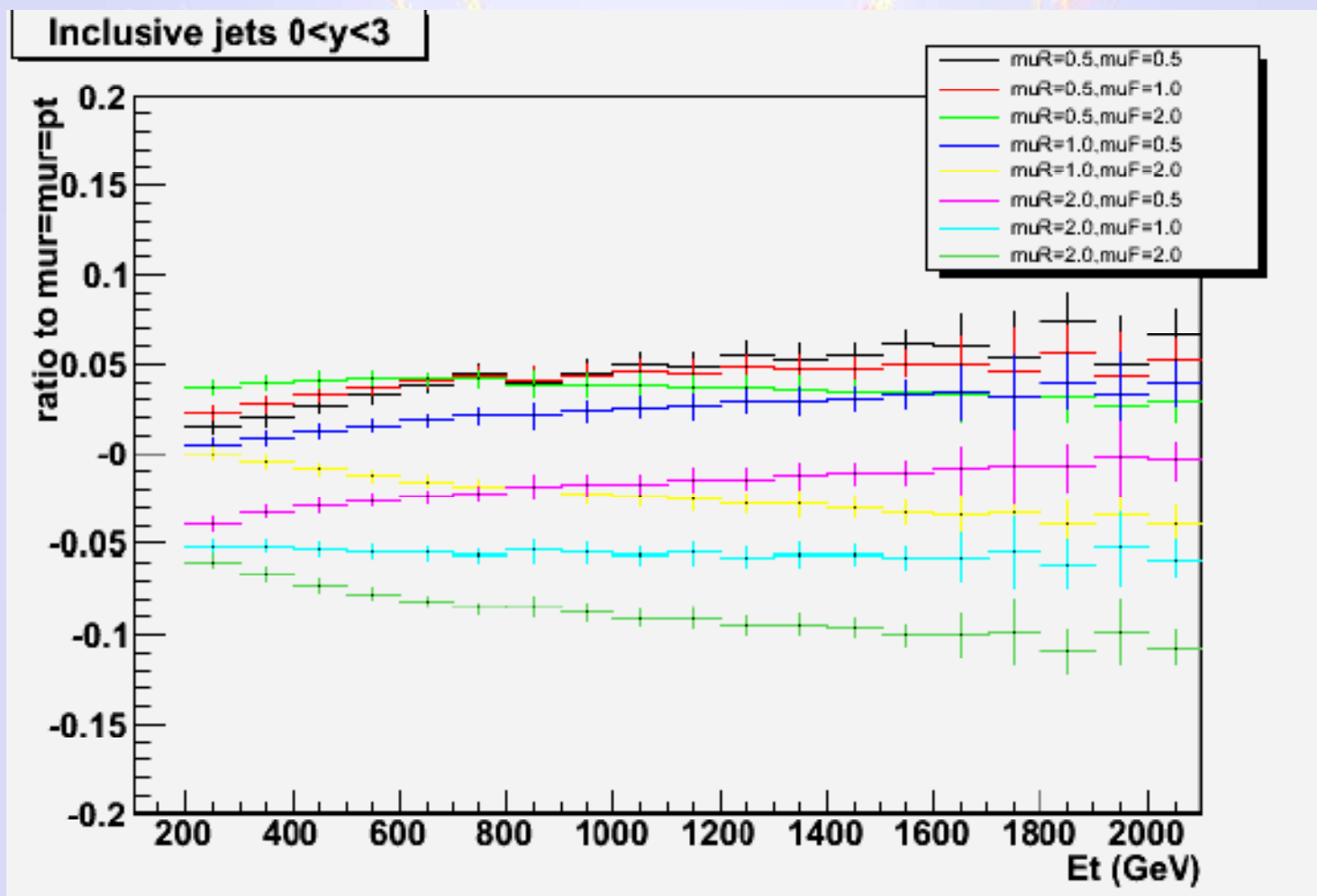
- QCD is a central field at LHC that requires attention
- Preparations to understand Jet Energy Scale well on the way
 - Complex task
 - All options left open to see what works best on data
- Inclusive jet cross sections require good control of experimental and theoretical errors
 - Experimental error dominated by JES
 - Theoretical error dominated by high x gluon PDF
 - Contributions to PDF from LHC data worthwhile
- Absolute LHC luminosity measurement via proton diffraction
 - Promises high precision
 - Roman pot detectors required
 - Design and testing well on the way



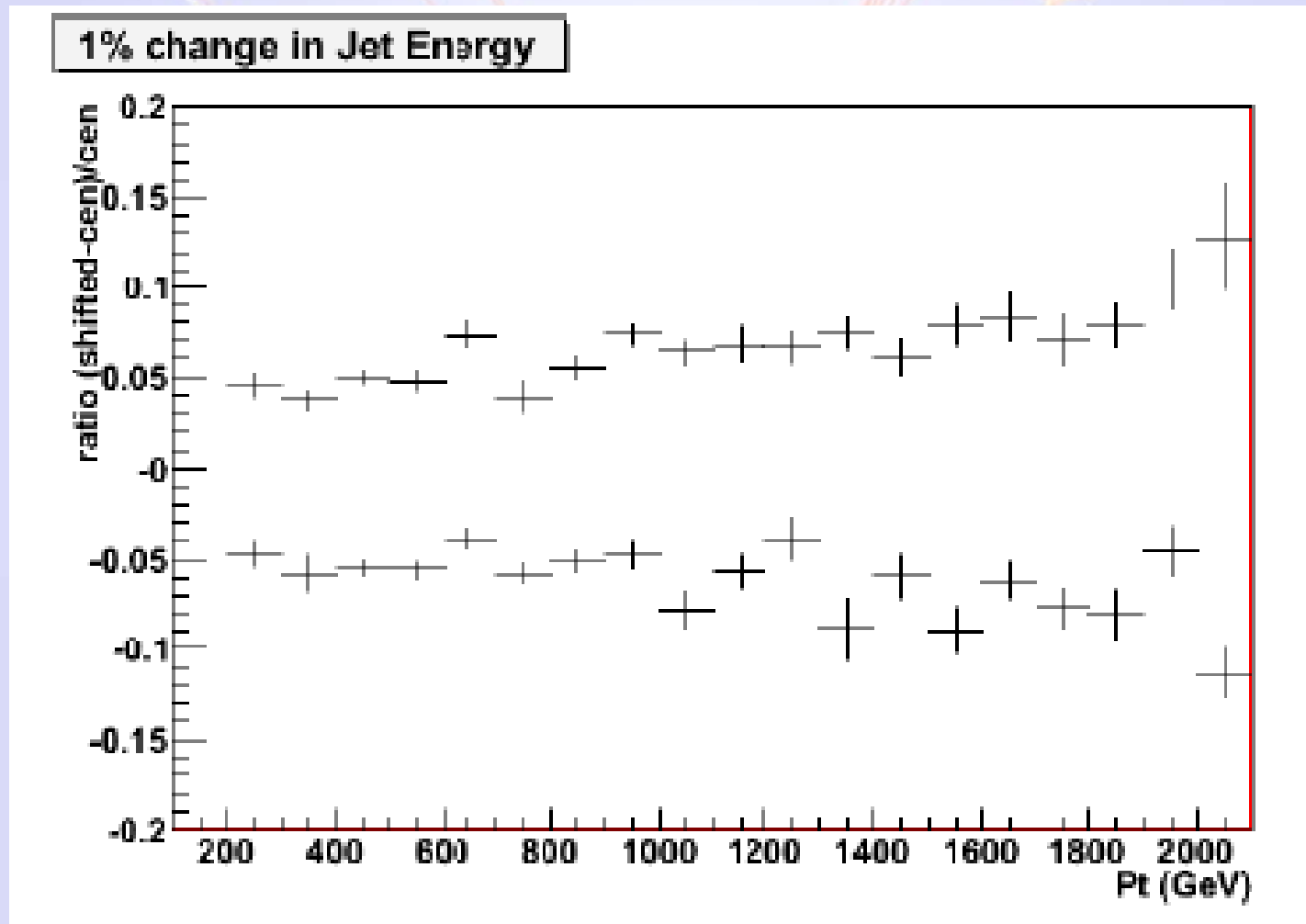
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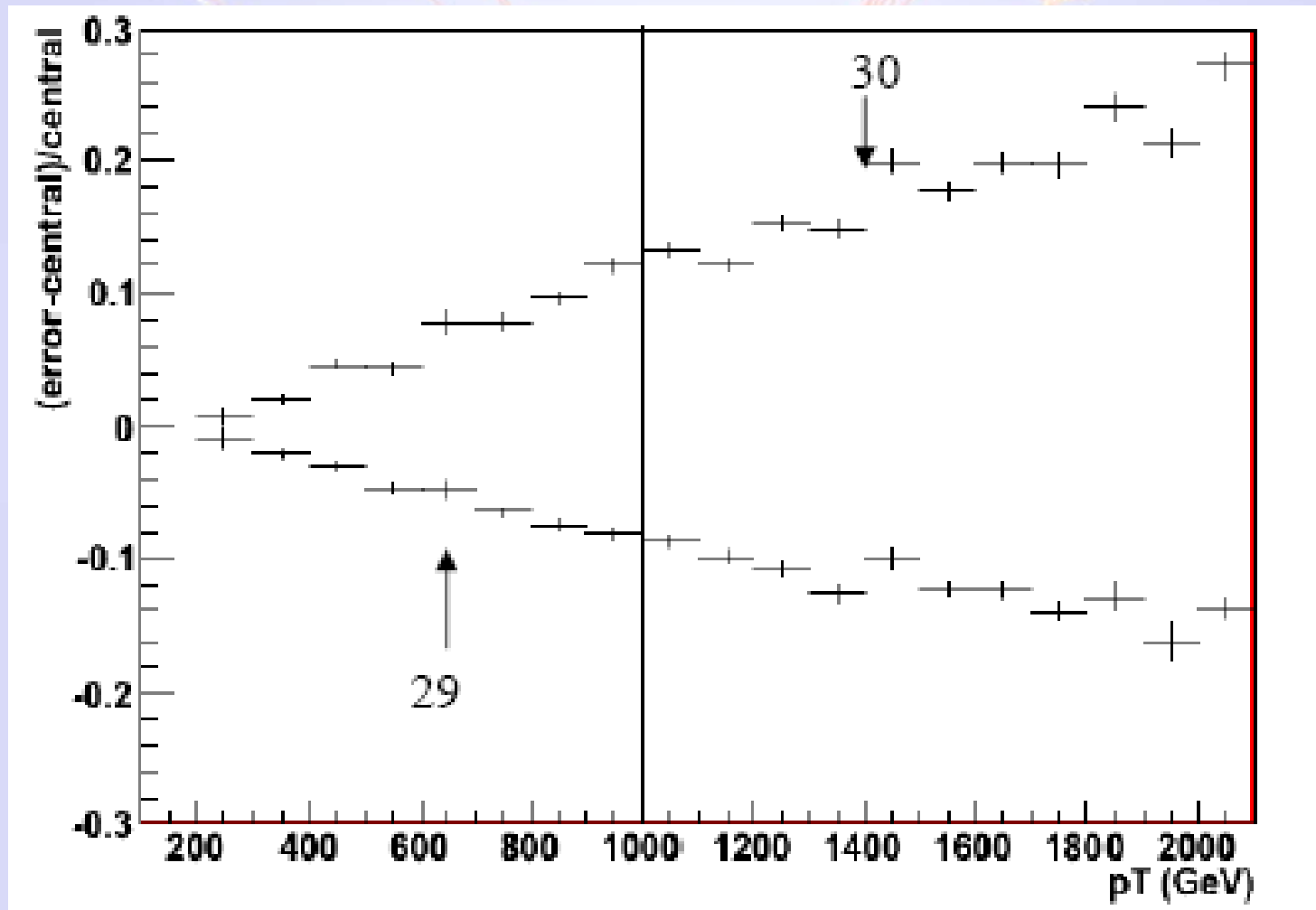
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